PROPORTIONAL COUNTER FOR X-RAY ANALYSIS

OF LUNAR AND PLANETARY SURFACES

FINAL REPORT

Grant NSG-7177

May 1, 1976 to June 30, 1977

(NASA-CR-158754) PROPORTIONAL COUNTER FOR X-RAY ANALYSIS OF LUNAR AND PLANETARY SURFACES Final Report, 1 May 1976 - 30 Jun. 1977 (Smithsonian Astrophysical Observatory) 14 p HC A02/MF A01 CSCL 03B G3/91

N79-27051

Unclas 27908

July 1979

Prepared for
National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

The Smithsonian Astrophysical Observatory and the Harvard College Observatory are members of the Center for Astrophysics

The NASA Technical Officer for this grant is Mr. Richard J. Williams, Code SL, National Aeronautics and Space Administration, Headquarters, Washington, D. C., 20546.

PROPORTIONAL COUNTER FOR X-RAY ANALYSIS

OF LUNAR AND PLANETARY SURFACES

FINAL REPORT

Grant NSG-7177

May 1, 1976 to June 30, 1977

July 1979

Prepared for
National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

The Smithsonian Astrophysical Observatory
and the Harvard College Observatory
are members of the
Center for Astrophysics

TABLE OF CONTENTS

1.0 INTRODUCTION

The objective of this program was to study a new type of X-ray detector known as the Proportional Scintillation Counter in the measurement of lunar and planetary surface composition by non-dispersive X-ray fluorescence analysis. X-rays interacting in pure xenon gas produce 1200-2000 Å radiation when the primary electrons drift in a high electric field. As reported in the literature by Policarpo, et al.[1] this new device offers significantly better energy resolution than a conventional proportional counter and thus has the potential of providing improved separation of elemental X-ray lines from Mg, Al, Si in non-dispersive analysis in the manner used successfully by the Apollo 15/16 X-ray fluorescence spectrometer. While its energy resolution is not as good as that of a solid state detector, it can be made in much larger areas and does not require cooling to low temperature. Therefore, it seems better adapted to long duration space missions that are weight limited. However, there are two difficulties that must be overcome before the detector can be developed for use in space. One, the gas must be maintained in a very clean condition or the UV scintillation is absorbed by impurities which are all materials other than noble gas. Two, the scintillation light must be detected in such a way by a photomultiplier (PM) that the signal amplitude from the PM tube is independent of the location of the X-ray. Otherwise, the resolution would be degraded by the finite distribution of the X-rays in space.

Two approaches are possible for achieving uniform light collection: (a) arrange to have the light generated at the same point independent of where the X-ray is absorbed, and (b) develop a position sensitive detector and calibrate the light amplitude as a function of where the X-ray interacts. As it turned out, there was a great deal of interest in the proportional scintillation detector among other X-ray astronomy groups as a new

instrument for the study of spectra of cosmic sources. In particular, the study of approach (a) was carried out by the High Energy Astrophysics Division of the Space Science Department of the European Space Agency in Nordwijk, The Netherlands and the Columbia Astrophysics Laboratory in the U.S. Consequently, we decided to follow approach (b), the development of a position sensitive proportional scintillation detector. If successful, this might be useful in applications involving X-ray imaging as well as spectroscopy. The support from this grant would be adequate only to see if a position sensitive gas scintillation detector could be developed.

2.0 DEVELOPMENT OF THE POSITION SENSITIVE GAS SCINTILLATION DETECTOR

2.1 GAS PURIFICATION SYSTEM

In order for xenon to scintillate, it is essential that it be free from contaminants. A laboratory apparatus was constructed to purify the gas by flowing through a commercial getter known as "Hydrox" manufactured by the Matheson Company. Cryogenic trapping with fractional distillation was used to reduce impurities further. In addition, an internal gettering system for the detector itself was studied. As shown in figure 1, these internal getters are doughnut shaped. They were placed in a cylindrical box that can be attached directly to the detector. They are manufactured by Saes Getters of Milan, Italy. The idea was that following purification through the laboratory apparatus, the detector would be filled with xenon and sealed off. The internal getters would maintain the purity of the gas in the detector from that point on against contamination from outgassing of internal materials and against air and water vapor in the laboratory environment which can backstream through leaks.

2.2 DETECTOR DESCRIPTION

The detector system is shown in figure 2. It was constructed by modifying the position sensitive proportional counter described by Gorenstein, et al.[2], and we refer

to it as the "Scintillating Imaging Proportional Counter." X-rays enter the detector through a thin window supported by a tungsten mesh against the two atmosphere pressure differential. The window mesh is supported in turn at 2" x 0.3" intervals by a fiberglass frame. A parallel electric field exists in region A between the window and the first of two fine meshes. X-rays are absorbed in region A (4.5mm) and primary electrons drift through the first mesh into region B (3mm). Originally we intended to operate the detector with region A strictly as an interaction and low field drift region and maintain region B at higher field values as the region of light production. The path length in region A is variable depending on where the interaction has taken place. The path length in region B is constant so that the amount of light produced should be independent of the point of interaction, thus preserving in principle the good energy resolution of the detector. However, drift of the electrons through region A degrades the spatial resolution because of their lateral diffusion. Thus in terms of spatial resolution, better results were obtained by increasing the field strength of A to 10,000 v/cm where it becomes the region of light production and supressing light production in B by lowering its field strength.

The light production region is imaged by a reflecting cassegrain telescope onto a readout system consisting of a UV to visible image converter and an image intensifier. Reflecting optics are preferable to refractive optics because the xenon light is actually UV radiation in the wavelength range 1450-2100 Å. At these wavelengths refractive focussing elements will be rather dispersive and produce chromatic aberration. The gas volume is isolated from the optics by a calcium fluoride window. Although it results in some chromatic aberration and absorbs half the light, the window was needed because the UV to visible image light converter could not operate in a pressure environment of two atmospheres. Ultraviolet radiation is converted to visible light by an ITT

F4122 proximity focus converter with a magnesium fluoride window. Its output is coupled by fibre optics to a simple commercial image intensifier. It is estimated that about 50 UV photons are imaged onto the converter for each 5.9 keV X-ray. With the combination of the converter, image intensifier and fast relay lens, a single 5.9 keV X-ray event can just barely be photographed on a fast recording film such as Kodak 2475. Alternatively, at the price of losing light the UV to visible converter could be omitted if a layer of wavelength shifter such as sodium salicylate is placed over the input to the optical image intensifier. To compensate for the absence of the UV to visible converter one might use a higher gain optical intensifier. The area of the detector is 10 cm x 10 cm but the image intensifier covers only the central 5 cm x 5 cm. Larger format detectors should have the same intrinsic resolution. The difficulty of larger area imaging lies principally in the increased size and complexity of the telescope system that images the light production region onto the readout system. The best method of reading out very large systems might be to space several small telescopes uniformly over the active area.

The detector's performance was studied with a two milicurie ^{55}Fe source of 1 mm diameter at a distance of 60 cm in vacuum from the window which was masked by various resolution patterns. From laboratory measurements, we estimate that the detector has a resolution of 0.5mm. Other ^{55}Fe measurements on the apparent diameters of 1.0mm holes in a resolution mask also give a value of 0.5mm for the overall performance. For these measurements light production took place entirely in region A.

The optical readout system makes a contribution to the 0.5mm resolution. The resolution pattern can be viewed directly by the system in UV light to obtain a value for the readout system resolution. If we assume that it and the intrinsic spot size of the light emission from an X-ray are in quadrature then the intrinsic spot size is estimated

to be less than 0.4mm. In these measurements the intrinsic size is in effect the intrinsic resolution of the detector. The limiting factor in the intrinsic resolution is the lateral diffusion of the primary electrons as they drift along the electric field. Xenon is expected to be considerably worse in this respect than argon because the drift velocity of the electrons is much lower. One should be cautious about additives that would increase the drift velocity because they would probably absorb much of the UV light produced by xenon. Figure 3 illustrates the effect of increasing the electric field in the drift region. The spatial resolution as estimated from the apparent diameter of 1mm holes is plotted as a function of voltage in region A while the field in region B remains approximately constant. There is an improvement in resolution with increasing drift voltage. In all cases resolution is best if there is minimum drift prior to light production.

3.0 CONCLUSIONS

The results of this study definitely prove that the light signal in a proportional scintillation detector remains well localized. With modest electric fields in xenon the primary electrons from a photoelectric absorption of an X-ray can be brought a distance of a few millimeters to a higher field region without spreading more than millimeter or so. Therefore it is possible to make a proportional scintillation detector with good position sensitivity that could be used to calibrate out the difference in light collection over its sensitive volume.

While the funding of this grant was not adequate to design and construct a readout system that has both good energy resolution and position resolution, the results are sufficiently encouraging for us to consider several approaches in the future.

4.0 OTHER APPLICATIONS

There are other potential applications for the scintillating imaging proportional counter. Its advantage over conventional gas proportional counters is its ability to handle very high instantaneous rates. Since no electron multiplication takes place, space charge effects are minimal. Thus, in conjunction with an X-ray telescope, microscope, or pinhole camera, it can record the X-ray image of a very short lived phenomenon such as may be created in high temperature plasma experiments. Recording the entire dispersed spectrum of a short lived plasma is also of great interest. The duration of the light flash from an X-ray is equal to the drift time of the primary electrons through the light production region. This is estimated to be about one-third of a microsecond per millimeter. Thus dynamic studies can be made of phenomena which vary on a time scale of a microsecond or longer. In comparison to other position sensitive X-ray detectors such as multi-channel plates (which have much better spatial resolution), diode arrays, or film, this device has at least one of the following advantages: over an order of magnitude larger quantum efficiency, larger format, and presumably much better linearity especially in studies of transient phenomena. Although we have not studied the behavior of the device at high instantaneous rates, the absence of electron multiplication does suggest that the device will be quite linear. A long focal length X-ray telescope or pinhole camera or high magnification microscope used in conjunction with a large format version of the present detector may achieve a spatial resolution that is adequate for many purposes. The advantage of higher quantum efficiency and linearity could be crucial in high resolution spectroscopy where the absolute strengths of X-ray lines are measured. The requirements of experiments that are either current or planned for Tokomak plasma machines seem to be compatible

with this detector. Finally, it is possible to imagine time dependent measurements in biology and medicine where the advantages of high light output per X-ray, presumed linearity, and good transient response would be important.

ACKNOWLEDGEMENTS

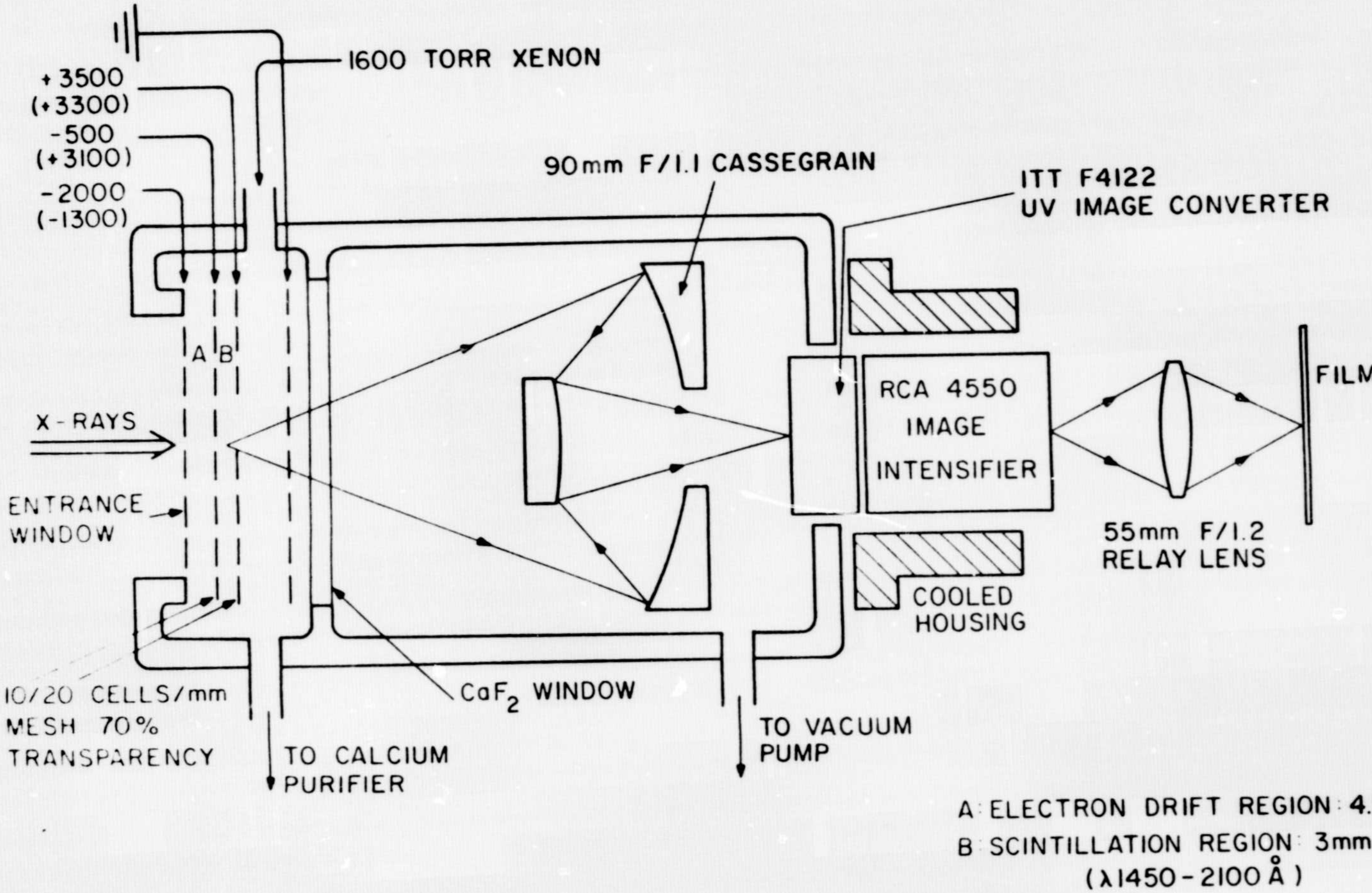
We would like to thank J. Hagopian of the laboratory staff of the Smithsonian Astrophysical Observatory for his aid. Also, we acknowledge our discussions with F.R. Harnden, Jr. of the Smithsonian Astrophysical Observatory in the design of the detector.

REFERENCES

1. A.J.P.L. Policarpo, M.A.F. Alves, M.C.M. Dos Santos, and M.J.T. Carvalho. Nuclear Instruments and Methods, 102, 337 (1972).

2. P. Gorenstein, H. Gursky, F.R. Harnden, Jr., A. DeCaprio, and P. Bjorkholm. I.E.E.E. Transactions on Nuclear Science, NS-22, 616 (1975).

Figure 1. Internal getters that could be used to maintain purity of xenon against outgassing from materials inside and backstreaming from leaks. The cylindrical box is attached to the side of the detector.



SCHEMATIC DIAGRAM OF SCINTILLATING-IMAGING PROPORTIONAL COUNTER

Figure 2. Schematic diagram of the Scintillating Imaging Proportional Counter. The numbers assigned to the entrance window, cathode and anode are voltages. The upper values are typical operating values for light production in region B. The lower values, in parentheses, refer to the situation where the spatial resolution is better.

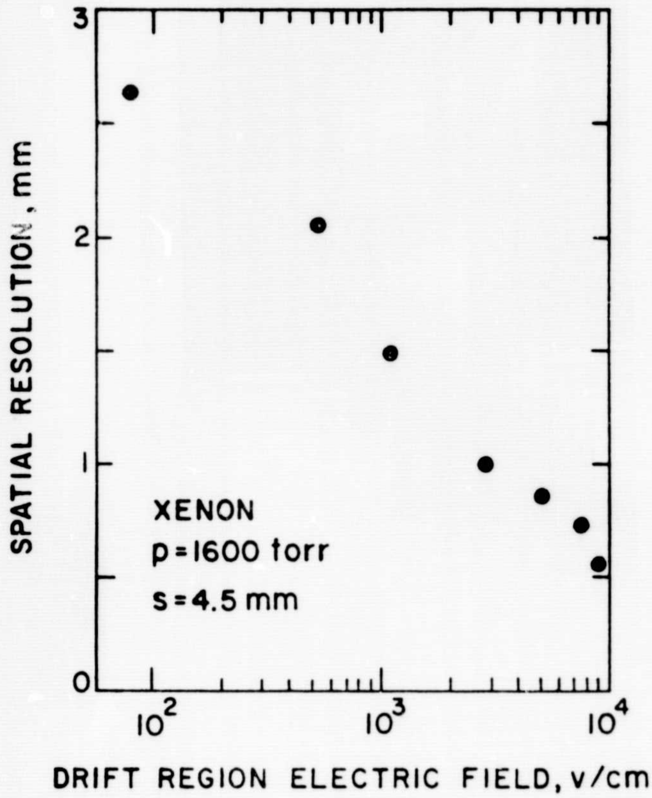


Figure 3. Estimated resolution of the Scintillating Imaging Proportional Counter as a function of electric field in the 4.5mm drift region. The improvement in resolution is due to decreasing electron diffusion.